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Impact of Treated Industrial Effluents on Yanbu (Red Sea) Coral Reefs and the Efficiency of Coastal Ecosystem Conservation

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Abstract

The coral reefs along the Yanbu had experienced destruction by the industrial development during 1980-1985. As a part of surveillance monitoring, the effluents collected at the inlet and outlet of IWTP were analyzed for 21 chemical parameters to detect industrial pollution. The efficiency of IWTP with condiserable reduction in chemical concentrations and few violations from industrial standards were detected. A coral recruitment study in the coastal area had revealed considerable recruitment of corals, but the corals were being over grown by algae, indicating a low survival rate for the corals. The impact of excessive sediment and phosphate load on the reduction of coral recruitment and live coral coverage, excessive growth of filamentous algae, changes in population diversity of coral reef fishes were also highlighted. The study had identified butterfly fish as an indicator species for water quality in the coral reef region.

1. INTRODUCTION

The Red Sea coast off the industrial city of Madinat Yanbu al Sinaiyah (MYAS) had witnessed major increase in development activities in recent years. Available information on land-based sources and activities affecting the Yanbu coastal environment and the main pollution sources include waste discharges from sewage treatment facilities, cooling water discharge into coastal region the from petro-chemical industries and oil refineries. There was an urgent need to update information on land-based pollution sources and activities affecting the marine environment as the health of Port Barrier Reef, which serves as a natural coastal protection for the city's King Fahid Port from waves and tide was threatened by the deepening of shipping channel. An environmental monitoring program was established within the Royal Commission for Jubail and Yanbu for the protection of the marine environment off Yanbu from land-based pollution sources and coastal destructive activities such as dredging for landfilling and development of ports and harbors. The major exiting concerns to coastal ecosystem health and coral growth are the discharge of treated wastewater from Industrial Wastewater Treatment Plant (IWTP) and the industrial cooling water through a common outfall canal into the shallow coastal region. Though comprehensive monitoring program has been implemented to ensure that the allowable limit of 32.1 C will not be exceeded in the vicinity of Port Barrier Reef and the wastewater discharges have to adhere to Royal Commission standards, violations of the regulations frequently occur.

In this study, the frequency of such violations and the intensity of violated chemical parameters were investigated. The characteristics of wastewater before treatment OWTP influent and after treatment OWTP effluent are studied for two years period. The coastal ecosystem adaptations to the excessive nutrient and thermal loads into the region along with other human activities were assessed by coral recruitment and growth study and by the population diversity in Port barrier Reef coral fishes.

2. MATERIAL AND METHODS

Each industrial facility, after pre- treating its wastewater to comply with the pre- treatment tandards, discharges the wastewater into the industrial wastewater treatment plant (IWTP). The central industrial treatment plant has rotating biological contactors and an activated sludge. At the present operational level, the IWTP plant treats 9000-12000 cu m/day, i.e., about 45 % of its design capacity of pre-treated (using the dissolved aeration system) industrial wastewater generated by the city. A dual media filtration system is provided as post-treatment, prior to final discharge. The wastewater samples from the outlets of each facility is collected on alternate days with the time of collection depending on the outflow rates of wastewater. The wastewater samples are also collected from the IWTP inlet on alternate days. The samples are analyzed for its characteristics as per the EPA guidelines. The seawater samples are collected from the outfall channel and its vicinity in coastal region and also from the Port Barrier Reef area on a monthly interval.

The samples are analyzed for the dissolved nutrients. The coral recruitment study using settling plates technique (Gracia, 1993) is

preformed at three sites on the Port Barrier Reef at depths of 5 and 10 m.

3. RESULTS AND DISCUSSION

3.1 Efficiency of Waste water Treatment Plants.

The total quantity of cooling water used by various industries is about 236000 cu m /day and will be increased to 350,000 cm m /day as per the five year master plan of RC. The quantity of cooling water used for the refinery plant, power plant and desalination plats are 55,000, 54,000 and 18000 cu m / day, respectively. A comprehensive monitoring program has been implemented to ensure that the allowable limit of 32.1 C will not be exceeded in the vicinity of Port Barrier Reef. Impacts from industrial effluents, in the form of thermal pollution from power and desalination plants and hypersaline brine water from desalination plants, constitute an important land-based source of pollution affecting coastal waters in the region. Discharges from power and desalination plants can alter temperature and salinity in the coastal region and highest recorded temperature and salinity during the 2 year study period was 32 C and 44%, respectively. In addition to power generation, the city have six 9,1120 cu m / day desalination units. They discharge non-contact cooling seawater and concentrated brine into sea, using an out fall channel. Each unit discharges about 3787 cu m / day of brine with a concentration of 5,0000 ppm and a temperature of 39 C. A flow rate of 15,900 cu m /day is received at the IWTP plant for treatment, where a good quality treated wastewater is generated. About 30% of treated wastewater are reused in industries and the rest discharged into Red Sea. The pollution load discharged into Red Sea have computed as TSS 32 tons/year, BOD 48 tons/ year, COD 196 tons/ year, oil and grease 35 tons/ year, NH3-N 2.4 tons/ year (UNEP, 1996). Ballast water having an average oil and grease content of 6.0 mg/l is also discharged into Red Sea. The average discharge rate into Red Sea is 4000 Cu m /day. The pollution load from ballast water in Yanbu region are, TSS 19.7 tons/ year, oil and grease 8.8 tons/year (UNEP, 1996).

A study conducted by MEPA / World Bank on the levels of different parameters in industrial waste water discharged to Red Sea had identified considerable amounts of COD, BOD, PO4-P and NH3-N in waste water discharges from Jeddah and null amounts in the discharges from Yanbu city. However, the recent study at Yanbu had revealed considerable violations of Royal Commission's pollution limits by IWTP. The details of such violations are given in Table (1).

The violation occurrence was more than 20% for TDS and chloride. As the wastewater is discharged to high saline Red Sea water, the chlorine values may not influence the coastal ecosystem. The phenol content, sulfide and sulfate had violation cases in the range of 10- 20%. The high sulfate violation percentage may of less danger to marine ecosystem. The BOD, pH, TSS, COD, Oil and grease, Cyanide, dissolved nutrients and trace metals in the treated waste water had violation histories of less than 5%.

Table 1: Details of violations of effluents from RC Standards. A- Parameter, B- RC Standards (mg/l), C - No. of Violations, D - Percentage of violations.

A	B	C	D
PH		16	1
TSS	15	10	3
TDS		62	21
BOD	30	2	1
COD	200	55	5
Oil	10	33	3
Phen	0.5	47	11
Cl	400	250	21
S+	0.1	132	14
CN	0.1	1	2
SO4	150	150	19
PO4	2	2	1
NH_4	3	1	16

The efficiency of the wastewater treatment plant IWTP was presented in terms of concentration reduction of various parameters. The percentage reductions for various chemical parameters are given in Table (2). A concentration reduction of less than 20% of the influent level was observed for TSS, BOD, Oil and grease, NH4, COD, Phenol and less 50% for sulfide. However, it was noticed that dissolved nutrients NO3, NO2 had an increase concentration level reaching upto 1500% in the treated effluent.

The reduction in the level of reactive phosphate was not much (88%). The discharge of wastewater with elevated plant nutrients can generate excessive growth of single celled organisms in the coastal wasters in the outfall vicinity and in Port Barrier reef area. The high algal growth at Gap and SE End could be the result of this nutrient enriched wastewater.

The sea water analysis during this study period had shown many occurrences of PO4-P violations of RC standard of 25ug at/l. The TSS in seawater also had a number of violations of RC standard though the IWTP had shown a reduction efficiency of 12% for TSS. The other nutrients such as nitrite, nitrate and ammonia in seawater had

not shown any violation of RC standards even in the case of a high enrichment of them by the IWTP.

Table 2: Percentage reduction of chemical parameters in treated effluents. A & C Parameters, B & D Concentration Reduction (%)

A	B	C	D
PH	103	PO_4	89
TDS	104	NO_2	331
BOD	10.9	NH_4	21
COD	14.2	Co	59
OIL	6.9	Cu	31
Phl	18.8	Fe	18
Cl	108	Mn	70
S+	43	Ni	118
SO_4	88	Pb	132

Table 3: Maximum observed levels in waste water discharges. A- Parameters, B- IWTP Inlet, C- Other Industries.

A	B	C
Tem	30	48
PH	9	12
TSS	182	312
TDS	2660	40488
BOD	209	470
COD	2280	4211
Oil	100	360
Phe	15	83
Cl	1060	40893
S+	2	30
SO_4	626	1413
PO_4	10	12
NO_3	0	3
NO_2	3	11
NH_4	0	15

The maximum observed concentration of the industrial effluents at IWTP inlet and at the contributing industries are given in Table (3). Though, some of the industries had very high levels for certain parameters at their outlet, the mixing of them in the leading pipeline to IWTP inlet had reduced such levels of most parameters by 50% of the maximum at the industries outlet and kept the parameters with in RC standards.

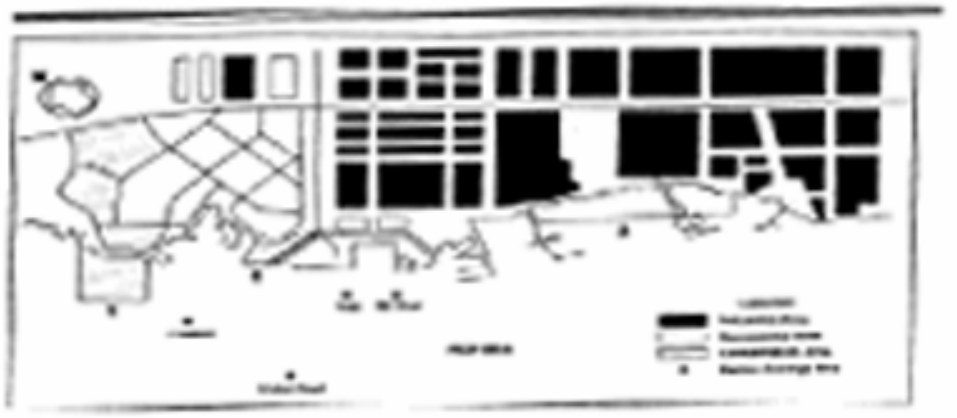

Figure 1: Port Barrier Reef of Yanbu (Saudi Arabia)

3.2 Coral Recruitment and Coral Cover Study.

In descending order of the degree of exposure to human activities, the investigation sites Figure (1) were represented by Control, SE End, and Gap stations, respectively, the last two stations being located at the Port Barrier Reef. It has been pointed out that a combination of extreme conditions, and especially the length of time that a set of extreme conditions prevails, is more important than simple extremes of a single environmental variable. Therefore, many species of corals in the area live close to their tolerance thresholds. The deviation of wastewater discharges from the RC standards on a number of occasions can put severe stress on the coral health in Port Barrier region. A coral recruitment study using settling plates was undertaken to identify the quality and density of corals recruited at the three sites to determine the factors that affect survival.

The Shannon diversity indices (Pielou, 1975) of fouling communities on the plates had yearly mean values of 2.92, 2.83 and 3.00 for Gap, SE End and Control stations, respectively, for the protected surface. The corresponding means for the unprotected plate surfaces were 2.49, 2.77 and 2.64 respectively. The inner protected surfaces of plates from control station appear to be more diverse, although the differences were statistically not significant.

The species diversity on unprotected surfaces at SE End (2.78) was greater than at the other two stations, but these differences were statistically insignificant. The bare space on the unprotected surfaces of plates at all stations and depths was greater than of the protected ones and the reason for this was attributed to fish bites and scarping on unprotected surfaces. Algal growth increased its foothold on the protected surfaces at all depths and stations except at SE End due to the prolific growth of hydroids (Table 4).

The number of hermatypic coral recruits to the reef margin plates, summed within 12-month experiment showed that 42-50% of plates exposed at control and SE End stations were recruited by corals, while only 25-30% was at Gap station. The number of coral recruits was highest at SE End (99 at 5m, 127 at 10m) and lowest at Gap station (10 at 5m, 23 at 10m). Fisher exact probability indicates a significantly better chance of recruitment for the SE End and Control plates. The survival of the settling corals on the recruitment plates may not always occur, even though conditions are favorable for rapid growth, as the corals grow more slowly than short- lived organisms such as filamentous algae. Although there were more recruitment of corals at SE End of Port Barrier Reef, the majority were over grown by fleshy algae and hence, had a very low survival rate.

The chances of survival were even less at Gap station as the nutrient (orthophosphate) was highest, with a mean of 3.37ug/l, Control station ranked second with 2.61 ug/l, while the SE End had the lowest mean value 2.50ug/l. The Gap and Control stations are nearer to the outfall channel carrying the treated wastewater from treatment plants and cooling water from power plants with an elevated nutrients content and higher than ambient temperatures; though there is no positive evidence that flow from the channel ever reaches the barrier reef. The Gap station seems to receive nutrient from the resuspended sediment created by shipping traffic through the barrier channel. The influx of excess nutrient, whether sediment born or from other sources, tend to determine the health of Port Barrier Reef.

The percentage of live coral cover at Gap station had not differed much (20.1-20.4) since 1985 with 28.9-32.7 for SE End and 23-34.5 for the Control station. However, there was a great difference in the composition of dominant coral Species. Visual observations had shown that many massive forms, such as Porites lutea and Goniastrea retiformis and table Acropora Hyacinthus, succumbed to environmental stress. What remains are their skeletal structures covered entirely with green algae. At Gap station during 1991, large massive forms of Porites sp. were almost entirely covered with sediment. Although there was an improvement in live coral percentage at SE End station; there were some segments where almost an entire reef area was covered with algae, especially the area fronting the service harbor. Control station, on the other hand, showed a satisfactory percentage of live coral (34.5%). It is interesting to note here that species composition was being influenced by environment, where opportunistic branching species such as Pocillopra verrucosa became dominant in the area.

3.3 Coral fish Population density

Line transect technique was used to count all the butterfly fish in each station. The species diversity and population evenness of a group of common reef fishes - namely, butterflyfish (Family Chaetodontidae) - at the three sites on Barrier reef indicated the indirect effect of coral reef health on the butterflyfish population (Table 5). Ten species were recorded during the survey; out of 14 species reported in the Red Sea. All the ten were found at Control station, while only six species at Gap station and seven at SE End. At least five species were present at all stations. The most common and abundant species of butterfly fish found was Chaetodon aurig. The Control and Gap stations were dominated by C. austriacus, while SE End was dominated by G. larvatus. Two species, C. melanotus and C. paucifasciates were only recorded at Control.

There was no significant difference in species diversity between Gap and SE End stations, which were subjected to man made environmental stress. However, a significant difference was found between these stations pooled values and with the Control station values. There was no significant difference in population evenness among the stations.

Table 4: Surface coverage of major fouling groups. A- Stations, B- depth (m), C- Surface, P- Protected, U- Unprotected, D- Bare Space, F- Fleshy Algae, G- Crustose Coralline Algae., A- Gap, S- SE End, C- Control.

A	B	C	D	F	G
G	5	P	15	42	28
		U	15	18	55
	10	P	16	38	19
		U	32	26	35
S	5	P	18	36	23
		U	22	40	28
	10	P	25	38	15
		U	42	25	24
C	5	P	21	45	16
		U	29	28	40
	10	P	28	35	23
		U	36	33	26

Many of the fish associated with the reef are extremely territorial. This is especially true for the Damselfish (Family - Pomacentridae) that maintain algal lawn. The results of a damselfish survey at the three sites in Port barrier reef showed (Tables 6 and 7) that the number of fish maintaining algal lawn was significantly greater at Gap station (1.92/sq.m) than at SE End (0.36/sq.m) and at Control station (0.56/ sq.m). There was no significant difference in population density between SE End and control stations. The high algal lawn percentage at the Gap station (51.3) compared to SE End (15.98) and Control (24.6) clearly indicates the influence of excessive nutrient fluxes into the coastal region from treated wastewater from IWTP and of the associated population densities.

4. CONCLUSIONS

The discharge of partially treated municipal wastewater poses a significant management problem as the excessive nutrient loads, especially phosphorus and nitrogen compounds, cause significant ecological changes. Results of coral reef surveys in Yanbu region had revealed a low coral cover and high algal growth, particularly at the Gap station in the Port Barrier Reef.

This indicates that the removal of living coral was not the only negative effect of sedimentation and other man-made environmental stresses.

It also had reduced the number of associated fish species proportionately, so that when the coral reef communities were damaged, one of the first fish populations affected by the disturbances was the coral feeder. For this reason, butterflyfish is a useful indicator of environmental quality.

This study also reflects that even if some environmental stresses were present at the Gap station, coral larvae could be still get recruited in the area. Though the results indicated a declining trend of coral recruitment at all the study stations, the Control station still had a wider range of corallum sizes compared with the other stations. The lowest number of recruited corals at the Gap station revealed that it can no longer support a wide variety of coral species.

The low species diversity and the quite unstable coral community were the result of heavy sedimentation rate due to man induced reasons. Although waste water treatment facilities are provided for all the refineries and data on the quality of the treated effluent is generally acceptable, the refineries poses a threat to the marine environment in the absence of adequately enforced regulations related to effluent discharges into the coastal and marine environment. It may be concluded that the problem of the physical alteration and destruction of habitats as a result of dredging and filling operations associated with urban expansion and industrial developments, constitute the main source of environmental deterioration and, should therefore, be given the top priority.

Table 5: Mean density of Butterfly fishes. A- Gap, B- Se End, C- Control., D- Density

Species	A	B	C
	D	D	D
C .auriga	2	2.2	3.9
C. austriacus	2.3	0.5	5.2
C. fasciatus	1.7	0.9	2
C. lineolatus	0.2		0.3
C. melanotus			0.9
C. paucifasciatus			0.2
C. semilarvatus		0.1	0.3
G. larvatus		3	0.1
H. intermedius	1.4	1.6	1.7
M. trifascialis	0.3	0.1	0.4
TOTAL	7.9	8.4	15

Table 6: Damselfish population densities with algal lawn cover. A- Gap, B - SE End, C - Control. AL- Algal lawn %, FS - Fish/sq.m

	A	B	C

	FS	AL	FS	AL	FS	AL
Nov	2.1	52	0.4	16	0.67	28
Dec	1.8	57	0.2	10	0.69	24
Jan	2.7	50	0.5	19	0.43	17
Mar	1.0	48	0.4	20	0.47	20
Jun	1.7	49	0.3	21	0.70	26
Sep	1.9	49	0.2	10	0.49	24

Table 7: Comparison of dominant species of Damselfish. B = Black damselfish (Stegastes nigricans), J = Jewel damselfish (Plectroglyphidodon lacrymatus)

	Gap	SE End	Control
Nov	94% B	71% B	97% B
Dec	95% B	68% J	93% B
Jan	92% B	60% J	88% B
Mar	98% B	60% J	94% B
Jun	99% B	66% J	97% B
Sep	94% B	50% J	72% B

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